TISSUE OXYGEN RECOVERY TIME DIFFERENCE IN FRONT AND BACK SQUATS

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DEDICATION

This thesis is dedicated to Katie Yakel. I could not have made it this far in school without the constant competitive push from you. And to my fiancé, Brittni Beeman, I could not have moved half way across the United States without your continuous love and support.

ABSTRACT

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Muscle oxygenation (SmO_2) has been studied through near-infrared spectrometry (NIRS) to describe the change in oxygen saturation within a muscle. The MOXY sensor is an inexpensive and mobile NIRS device. The purpose of this study is twofold: first to determine if SmO_2 recovers faster when comparing individual hamstring or quadricep muscles and second to determine if SmO_2 recovers faster when comparing front or back squats at 70% of an individual's measured 1-repetition maximal (1-RM) weight. Eleven recreationally trained participants completed the study. Each participant performed a 1-RM test and another test at 70% of their 1-RM for both front and back squats. Data was collected during the 70% of 1-RM test by placing MOXY sensors on the vastus lateralis and biceps femoris of the left and right legs. SmO_2 recovery rate was reported as the rate constant by performing a linear regression from 10-50 seconds of each resting period. A repeated measures ANOVA was used to determine whether there were significant differences in SmO_2 recovery rates. The level of significance was set at $p < .05$. There was a significant difference of muscle type in each of the three rest periods of both the left and right legs (Right Leg 1st rest period: $F(1,9) = 5.708$, $p = .041$, Right Leg 2nd rest period: $F(1,9) = 8.781$, $p = .016$, Right Leg 3rd rest period: $F(1,9) = 9.609$, $p = .013$) (Left Leg 1st rest period: $F(1,10) = 6.466$, $p = .029$, Left Leg 2nd rest period: $F(1,10) = 5.952$, $p = .035$, Left Leg 3rd rest period: $F(1,10) = 14.754$, $p = .003$). The quadricep muscles had a greater recovery rate mean when compared to the hamstring muscle. With the greater recovery rate in quadricep muscles, this may suggest a faster recovery due to metabolic pathways, greater blood delivery, greater capillarization, or increased muscle activation compared to the hamstring muscles during the lifts.

KEY WORDS: Front squat, Back squat, Hamstring, Quadriceps, Muscle oxygenation, Recovery rate

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CHAPTER I

Introduction

Fundamental movement skills are critical for maintaining a normal lifestyle. By definition, fundamental movement skills are simplified movements that are able to be built upon to perform more complex movements (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). Mastery of these movements allow children and adolescents to produce the more complex movements that are observed in physical activity and competitive sports. Squatting is one of these fundamental movements that is essential for activities in everyday living. For example, squats are utilized as a person sits in a seat or picks an object off the ground. Also, squats can be built upon to form a more complex weight lifting movements such as a power clean or a snatch.

In the field of strength and conditioning, squats are frequently used exercises as several large muscle groups are utilized during this one exercise. The word “squat” is an umbrella term used to describe multiple exercises using similar movements. A properly performed squat will change the relative and absolute angles of the hip, knee, and ankle joints. Squats normally have flexion at the hip, knee, and ankle joints during descent phase followed by extension at the hip, knee, and ankle joint during ascent phase. Despite different variations of squats, most forms of squats intend to target the major muscle groups of hamstrings, quadriceps, gluteus maximus, and gastrocnemius (Haff & Triplett, 2016). As part of a training program, a properly performed squat is intended to build the muscles of the lower extremities (ankles, knees, hip, and lower back) in one exercise (Myer et al., 2014).

The two major variations of squats are back and front squats. Both, back and front squats begin with an individual standing in an erect position with their feet flat against the floor, shoulder width apart, hips and knees in neutral position (Gullett, Tillman, Gutierrez, & Chow, 2009; Myer et al., 2014; Schoenfeld, 2010). During back squats, the barbell is positioned across the back, resting on the trapezius and posterior deltoid muscle. During front squats, the barbell is positioned across the chest at clavicle height, resting on the major pectoralis and anterior deltoid muscle (Myer et al., 2014). The descent phase starts the squat movement as flexion occurs at the hip, knee, and ankle joints. The ascent phase starts when the hip joint is level with the knee joint and is completed through extension of the hip, knee, and ankle joints until reaching the original starting position (Gullett et al., 2009; Schoenfeld, 2010; Vakos, Nitz, Threlkeld, Shapiro, & Horn, 1994).

A significant amount of energy is required in a squat movement by the lower extremity muscles. Therefore, a high level of oxygen delivery to those muscles is necessary to sustain repeated contractions and recovery (Pittman, 2002). Saturated tissue muscle oxygenation (SmO_2) is the absolute measure of oxygen concentration in hemoglobin (Hb) and myoglobin (Mb) (Pittman, 2016). Hemoglobin is an oxygen transporting molecule in the blood, whereas myoglobin is an oxygen storing molecule in the muscle. SmO_2 is a major tool for assessing two determinates (O_2 delivery and O_2 utilization) of the muscle during exercise (Jones, Chiesa, Chaturvedi, & Hughes, 2016). SmO_2 is reported as a single percentage of both oxygenated Hb and Mb, at the point at which oxygen is being transferred from the capillaries into tissues.

Total hemoglobin (THb) is the non-absolute reported amount of hemoglobin and myoglobin in tissue (Myers, McGraw, George, Mulier, & Beilman, 2009). THb is different than blood Hb concentration because the location of the measurement is taken at the target muscle rather than in the blood stream. The measurement of THb is affected by four factors: blood Hb concentration, fat layer thickness, density of Mb concentration in muscle, and volume of blood in muscle (Ferrari, Muthalib, & Quaresima, 2011). The major use of THb when studying muscle oxygen kinetics is to help indicate whether blood volume is increasing, decreasing, or staying the same.

SmO_2 and THb can be measured using near-infrared spectroscopy (NIRS) and provide useful information about the oxygen demands of specific muscles. A mobile NIRS system, MOXY monitor (Fortiori Design Hutchinson, MN), provides a non-invasive and wireless way of measuring oxygen demand during exercise. MOXY sensors function by emitting light at wavelengths between the ranges of 680 to 850 nm into the skin. The wavelengths are then detected at 25 mm and 15 mm away by two different sensors.

Having the ability to measure SmO_2 with an NIRS devices provides insights into two different energy pathways: oxidative phosphorylation and anaerobic adenosine triphosphate (ATP) production (Hamaoka, McCully, Niwayama, & Chance, 2011). Oxidative metabolism is heavily relied upon during activities requiring low to moderate levels of intensity. As exercise intensity increases, so does the rate of oxidative metabolism, and a concomitant decrease in SmO_2 is observed. (Belardinelli, Georgiou, & Barstow, 1995; Belardinellii, Barstow, Porszasz, & Wasserman, 1995).

Purpose of the Study

The purpose of this study is twofold: 1) to determine if SmO_2 recovers faster when comparing hamstring to quadricep muscles and, 2) to determine if SmO_2 recovers faster when comparing front or back squats at 70% of an individual's calculated 1-RM weight of each designated lift.

Significance of the Study

This study can provide insight into how the hamstring and quadriceps muscles recover during each squat form. SmO_2 can help detect fatigue and that information can be utilized to improve performance. High-intensity training is well documented as a way of maintaining muscle health. Resistance training with a load of at least 70% of 1-RM is recommended by the American College of Sports Medicine (ACSM) to stimulate hypertrophy of muscles. The ACSM also recommends 2-3 minutes of rest between sets (American College of Sport Medicine, 2014). In high-intensity interval training (HIIT), individuals focus on high energy output with small rest duration. This form of exercise training has become quite popular due to the health benefits that may be gained in a short duration of time (Zuhl & Kravitz, 2012). Society has become fascinated with discovering the quickest method possible to achieve the greatest results. Research from the current study can be applied to individuals performing HIIT or similar short duration rest workouts and help better understand how much recovery is needed between sets of squats.

Information from the study may also aid in injury prevention. For example, knowing how quickly SmO_2 depletes and recovers may help people anticipate the onset of fatigue and loss of form. Individuals participating in exercise who do not take adequate recovery between sets/intervals may be more susceptible to injury. For example, if a collegiate athlete is trying to get in a quick workout in-between classes, then prescribing the faster recovery squat may be better suited for that individual athlete to reduce the possibility of injury.

Null Hypotheses

a. There are no significant differences in SmO_2 recovery rates between front squats and back squats.

b. There are no significant differences in SmO_2 recovery rates between hamstring and quadricep muscles in each individual lift.

Limitations

The sample size of this study was smaller (n=11) than the calculated effect size. Certain students or employees may not have chosen to participate for different reasons. One possible eliminator may have been the duration of the research study. The data collection for each individual took approximately three hours. The three hours were broken up into four different sessions of 45-minute time blocks and each testing session was separated by 48 to 96 hours. Another reason individuals may not have participated were the requirements of the research study. The research study required students to be recreationally trained for at least 6-months (self-reported), required the performance of multiple 1-repetititon maximum assessments, and an arterial occlusion. Finally, researchers did not correct form of participants because participants were self-reporting to have at least 6-months of prior weight training experience.

Definitions

BF. Biceps femoris

EMG. Electromyography

HB. Hemoglobin

Mb. Myoglobin

MOXY sensor. A completely wireless near-infrared spectroscopy device utilizing ANT+ for communication

NIRS. Near-infrared spectroscopy

SmO_2. Saturated tissue oxygenation

THb. Total hemoglobin

VL. Vastus lateralis

CHAPTER II

Literature Review

Near-Infrared Spectrometry

Muscle oxygenation has been studied through NIRS to describe the change in oxygen within a muscle. NIRS is non-invasive and can detect localized muscle hypoxia during exercise (Scott, Slattery, Sculley, Lockie, & Dascombe, 2014). NIRS is a valid and reliable popular tool for exercise scientists to monitor muscle oxygenation (La Mantia, Neidert, & Kluess, 2018; Scott et al., 2014). In a recent review, NIRS was recommend as an optical technique to measure and observe SmO_2 during and post-exercise (Ferrari et al., 2011).

During shallow squatting, NIRS showed stable SmO_2 values in the left lateral gastrocnemius muscle (Rittweger, Moss, Colier, Stewart, & Degens, 2010). Edlbeck, Dorman, Malek, & Snyder (2011) concluded in a research study that SmO_2 can be used as a method of determining leg preference when performing split squats. Participants in the study were trained athletes who performed 3 sets of 15 repetitions with only 1-minute of rest between sets while measuring SmO_2 in the left and right vastus lateralis. While this study identified a quadricep and a calf muscle to determine leg preference, it lacked any data from other major muscles involved during a squat such as the hamstring muscle.

NIRS has also been utilized to monitor SmO_2 in clinical populations (Erickosn, Ryan, Young, & McCully, 2013; Wakasugi et al., 2018). Waskasugi et al. (2018) investigated SmO_2 in allogeneic hematopoietic stem cell transplantation (allo-HSCT) patients during isometric contraction at 50% of maximal voluntary contractions. The study showed a decrease in SmO_2, but researchers suggested the decrease could be associated to a reduction in exercise capacity.

MOXY Sensors

Original NIRS machines were large in size and were limited to laboratory use. However, laboratory experimental research is limiting when transitioning to normal activity environments. NIRS technology has complemented the progression of technology but were still limited due to wired connection to the control box (Simmons, 2017). MOXY sensors are completely wireless and allow participants to perform movements with the least restriction and with more natural movement. At low to moderate levels of intensity, Crum, O'Connor, Van Loo, Valclx, & Stannard (2017) concluded MOXY sensors to be reliable at measuring SmO_2.

In a recent study by McManus, Collison, & Cooper (2018), two portable wireless NIRS devices (PortaMon and MOXY) were compared during dynamic conditions and at rest. Both the PortMon (Artinis Medical System, Netherlands) and MOXY sensors communicate through ANT+ to their software and require no wired connection during testing. Both NIRS sensors indicated similar and reliable tissue oxygen saturation index (TSI) values at rest and exercise. During exercise researchers state the values are not comparable between the devices due to the lack of arterial occlusion in the study.

Kodejška, Michailov, & Baláš (2015) utilized MOXY sensors to compare SmO_2 changes during forearm isometric contractions between individuals who participate in two different types of rock climbing. Each testing group performed a series of various forearm strength test to simulate isometric forearm contractions during rock climbing. Only one MOXY sensor was placed on the forearm for measurement. Results concluded a lower deoxygenation in one type of rock climber compared to the other. With measurements sites being the same, lower deoxygenation levels suggest different metabolic pathways or different training attributes.

Fatigue/Recovery

Fatigue during resistance training can be attributed to either central (neuronal) or peripheral (muscular) origins (Gandevia, 2003). Central fatigue is related to the central nervous system decision to stop the exercise (Gandevia, 2003). Peripheral fatigue is related to muscular system failing and resulting inability to continue exercising (Fitts, 1994).

In a study conducted by Hoffman et al. (2003), researchers monitored vastus lateralis change in SmO_2. Participants performed 4 sets of squats at two different intensities (15 repetitions at 60% of 1 RM and 4 repetitions at 90% of 1 RM) with 3-minutes of rest in-between sets. Researchers concluded there was a longer duration of re-oxygenation at lower intensity resistance. This result may be attributed to a higher lactate concentration produced during higher repetition exercises.

Paolo et al. (2001) investigated muscle fatigue in the quadricep and hamstring muscles in anterior cruciate ligament (ACL) deficient participants via electromyography (EMG). Utilizing an EMG system (Bagnoli, Delsys, Boston, MA), sensors were placed on biceps femoris, rectus femoris, vastus lateralis, and vastus medialis muscles of one leg. Participants performed 30 squats to about 90 degree of knee flexion on a computer-interfaced dynamometer. Researchers concluded there was greater fatigue shown in the quadricep muscles than hamstring muscles when comparing the instantaneous median frequency of the control group and ACL deficient group. Similar findings of quadricep muscle fatigue were reported by Azuma, Himma, & Kagagya (2000).

Azuma et al. (2000) examined SmO_2 in the rectus femoris and vastus lateralis during knee extensions. Researchers determined the vastus lateralis reported lower SmO_2 values at each testing interval when compared to the rectus femoris. The lower values in the vastus lateralis may be associated to the muscle fiber composition.

Injury risk increases as a decline in knee proprioception occurs from the result of muscle fatigue (Lattanzio, Petrlla, & Fowler, 1997). In a previous study, both an active and passive test of joint position sense have been affected negatively due to muscle fatigue (Allen, Ansems, & Proske, 2007). Multiple research studies have been conducted using NIRS investigating fatigue and recovery by observing SmO2 (Hettinga, Konings, & Copper, 2016; Jones et al., 2016). However, the use of the NIRS to compare SmO_2 properties in the quadriceps and hamstrings has not been reported in parallel front or back squats.

Biomechanics of Squats

There has been a fair amount of research conducted looking into the biomechanics of different variations of squats (Cotter, Chaudhari, & Jamison, 2013; Flores, Becker, Burkhart, & Joshua, 2018; Gullett et al., 2009). Gullett et al. (2009), investigated tibiofemoral joint kinetics and overall muscle recruitment during front and back squats. This study consisted of 15 trained individuals performing front and back squats, while measuring muscle activation with EMG and net force/torque using a combination of force data and video. Results demonstrated greater knee compressive force and knee extensor movement in back squats. Front squats produced significantly smaller knee compression forces and extensor movements with similar overall muscle recruitment.

Flores et al. (2018) examined peak knee extensor moments in different squat depths (above parallel, parallel, and full depth) and varying loads (0%, 50%, and 85% of 1 RM). Randomized depths and loads were assigned to 19 female participants. Peak knee extensor moments are significantly greater at full squat depth when compared to above parallel and parallel squats. Researchers concluded individuals concerned about knee compressive forces should perform less depth squats for reduction of injury possibility.

Muscle Activation

Muscle activation is a well-known research field utilizing EMG in resistance training. In early EMG research, there was a higher emphasis placed in tracking quadricep muscle activation due to the utilization of squats to strengthen quadricep muscles (Gryzlo, Patek, Pink, & Perry, 1994; Isear, Erickson, & Worrell, 1997). Caterisano et al. (2002), assessed the difference in muscle activation of 4 superficial thigh muscles (vastus lateralis, vastus medialis, biceps femoris, and gluteus maximus) at 3 squat depths (partial squat, parallel squat, and full squat). Participants choose a comfortable weight to perform all 3 squat depths. Testing order was randomized, and each participant performed 3 repetitions of each squat depth with a 3-mintue rest in-between sets. Results showed that there was only a significant increase in muscle activation in the gluteus maximus as squat depth increased. This study lacked weight standardization across participants. Multiple testing sessions with increased repetition count and set count could have enhanced the study, giving a more detailed picture of muscle activation.

Slater and Hart (2016) investigated muscle activation in 5 lower extremity muscles (vastus lateralis, vastus medialis, biceps femoris, rectus femoris, and gastrocnemius) using EMG. The study consisted of 25, untrained individuals performing 5 bilateral squats intentionally displacing the knee medially, anteriorly (heels off the floor), and with controlled alignment. Both displacement of the knee medially and anteriorly squats were compared to the controlled alignment squats. During both squats displacing of the knee medially and anteriorly, decreased muscle activation in the rectus femoris, vastus medialis, and vastus lateralis during initial decent and final accent. Only during squats displacing of the knee anteriorly, was an increase of muscle activation observed at initial accent of the rectus femoris, vastus medialis, and vastus medial. Therefore, an increase in muscle activation may occur due to compensation for improper technique.

CHAPTER III

Methods

Participants

Participants (n=11) in the study were volunteers with at least 6-months of current weight training and were between the ages of 18 and 35. Participants were not compensated for their participation in the study and were recruited via flyers and word of mouth from the Principal Investigator (PI) and Co-PIs. Potential participants were excluded due to indications in their health history questionnaire that placed them at higher than normal physical activity risks. Potential participants who were pregnant or unable to speak and communicate in English were also excluded. All study procedures and materials were approved by the Institutional Review Board of Sam Houston State University.

Experimental Procedures

This study required two sessions of assessment and two sessions of testing. Before participating in this study, participants read and signed an informed consent form and completed a brief health history questionnaire to ensure the safety of participation. Participants were communicated to not engage in any strenuous activity 24 hours before each session. Participants' height (meters) was measured on a standard balance beam scale and waist circumference (centimeters) measure with a tape measure. Date of birth was recorded. A body composition test on the Seca mBCA 514 scale (Seca; Hamburg, Germany) was administered next (See Body Composition Testing and Figure 3 for details). The order of testing (front vs back squat) was randomized. For the assessment, participants began with a 5-minute cycling warm-up on a stationary bike and 6 stretches.

Once the warm-up was completed, participants performed 3-5 practice repetitions of their designated lift with the bar weight only. Participants' parallel squat height was then measured and set (See Squat Protocol). Participants then performed weighted squats, progressing to their 1-repetition max weight (See Table 2). After completion of their 1-repetition max, participants engaged in a 5-minute cycling cool down on a stationary bike. Participants then scheduled their testing session to be performed between 48 to 96 hours after completion of assessment session.

For the testing session, researchers placed MOXY sensors (mobile NIRS device) (See Figure 1) on both the left and right legs located on the participants biceps femoris (BF) and vastus lateralis (VL) using adhesive tape and wrap (See Table 1 for reference positioning of MOXY sensors). Based on an EMG study by Rainoldi, Melchiorri, & Caruso (2004), MOXY sensor placement were choose by the most reliable reading sites for a hamstring and quadricep muscle. MOXY sensors were set to measure muscle oxygen at a fast pace (0.5 seconds update, no smoothing). Participants' parallel squat height was re-measured and set for testing session. Participants then performed an identical warm-up as the assessment session before testing. Once the warm-up was complete, participants performed a warm-up set of 3 to 5 repetitions of their body weight. Next, participants performed 3 sets of 15 repetitions at 70% weight of their one-repetition max weight with a 2 to 3-minute rest (sitting) in-between sets. After the final set, participants rested for 5-minutes. Once resting was complete, participants engaged in 5-minute cycling on the stationary bike. Next, participants had an occlusion test performed by wrapping a blood pressure cuff around their upper thigh for 5-minutes at 150 millimeters of mercury (mmHg) (See Figure 2). This was only done on one of the testing sessions. Participants then were scheduled for the second assessment and testing session. The second assessment and testing session are methodically conducted the same, as described above except for the other designated lift (front or back squat).

Table 1

Moxy Sensor Placement

Muscle	Anatomical landmarks and reference line	Intervention zone position along the reference line
Biceps femoris	The percentage distance from the ischial tuberosity to the lateral side of the popliteus cavity, staring from the ischial tuberosity	35.3 percentage of measured length or below blood pressure cuff
Vastus lateralis	The distance (mm) along a line from the superior lateral side of the patella to the anterior superior iliac spine, starting from the patella	94.0 millimeter

Note. Moxy sensor reference placement position on left and right legs for participants (Rainoldi et al., 2004).

Table 2

One-Repetition Maximum Protocol

1. Instruct the athlete to warm up with a light resistance that easily allows 5 to 10 repetitions
2. Provide a 1-minute rest period
3. Estimate a warm-up load that will allow the athlete to complete 3 to 5 repetitions by adding
    a. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercise.
4. Provide a 2-minute rest period.
5. Estimate a conservative, near-maximal load that will allow the athlete to complete two or three repetitions by adding
    a. 30 to 40 pounds (14-18 kg) or 10% to 20% for lower body exercise
6. Provide a 2- to 4-minute rest period
7. Make a load increase:
    a. 30 to 40 pounds (14- 18 kg) or 10% to 20% for lower body exercise
8. Instruct the athlete to attempt a 1 RM
9. If the athlete was successful, provide a 2- to 4-minute rest period and go back to step 7. If the athlete failed, provide a 2- to 4-minute rest period; then decrease the load by subtracting
    a. 15 to 20 pounds (7-9 kg) or 5% to 10% for lower body exercise.

Note. (Haff & Triplett, 2016).

Figure 1. MOXY sensor. A device used to measure changes in SmO_2 using the technique of NIRS.

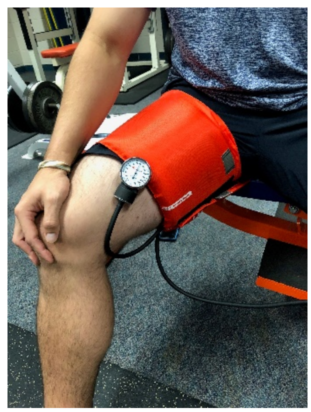

Figure 2. Arterial Occlusion.

Body Composition Testing

Body composition testing was conducted on Seca mBCA 514, a bioelectrical impedance analysis (BIA) device. Participants were required to wear light weight apparel, empty their pockets, and remove their socks and shoes for accurate body composition analysis. Participants' height and waist circumference were taken. Next participants stepped onto the Seca mBCA to measure their weight and input their height. While standing on the Seca mBCA 514, participants underwent a 20-second bioelectrical impedance analysis and then waist circumference (measured earlier) was inputted into

Seca mBCA 514 for analysis of body composition. Once completed participants received a detailed printout.

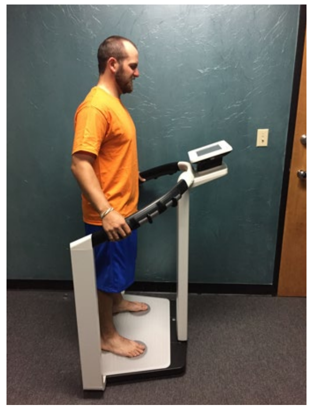

Figure 3. Body composition testing on Seca mBCA 514.

Squatting Protocol

For all assessment and testing sessions at least 2 trained spotters were used, along with safety lifting pins set at participants' knee height. Rack hooks and barbell were set at 80% of the participants' measured height. All lifting plates and barbell used for assessment and testing sessions were individually weighed and marked to the nearest tenth (0.1) of a kilogram. Parallel squat starting position was 0° knee flexion and stopping position was at 90°knee flexion (femur parallel to ground) measured with a goniometer placed at the knee joint. For consistency of parallel squats, a line of tape was set at 90°knee flexion height for participants to touch at the end of the descent phase of a squat and mark beginning of the ascent phase of a squat. If the participant could not feel the tape when squatting, then one spotter would verbally notify participant of when the tape was touched. See figures 4 and 5 for testing session set up and examples of front and back squats.

Figure 4. Back squat. Included in the picture is an example of how the squat height was marked and how the testing area was set up.

Figure 5. Front squat. Included in the picture is an example of how the squat height was marked and how the testing area was set up.

Statistical Analysis

Descriptive statistics were presented as mean ± standard error (SE). Data was collected on PerfPro Studio (version 5.81.10) (Hartware Technologies, Rockford, MI) and analyzed in SPSS (version 22) (IBM, Armonk, NY). SmO2 recovery rate was reported as the rate constant by performing a linear regression to find the rate constant from 10-50 seconds of each resting period. Repeated measures ANOVA was used to determine whether there were significant differences in SmO_2 recovery rates.

Significance was set at $p < .05$.

CHAPTER IV

Results

A total of 11 participants (5 females, 6 males) between the ages 18-35 years (mean of 24, standard deviation of 5) participated in the study. During the third set of front squats participants 1, 5, and 11 failed to complete 15 repetitions due to fatigue (P1: 10 repetitions, P5: 11 repetitions, P5: 11 repetitions). Data was only discarded due to equipment failure. Erratic MOXY sensor readings resulted in a few data point dismissals from the data analysis for the results section. In the first rest period, data from participants 4 (FS Right BF) and 6 (FS Right VL) were excluded. In the second rest period, data from participants 3 (BS Right VL) and 8 (FS Right VL). In the third rest period, data from participant 8 (BS Right VL and BF) were excluded. A 2(Squat Type: Front vs. Back) x 2(Muscle Type: Hamstring vs. Quadricep) repeated measures ANOVA between subjects was conducted to study recovery time differences. Separate data analysis was conducted on the left and right legs.

Right Leg Analysis

For the first recovery period (n=10); there was not a significant main effect of squat type, $F(1,9) = 2.575$, $p = .143$. The was a significant main effect of muscle type, $F(1,9) = 5.708$, $p = .041$. There was a significant difference between the interaction of squat type and muscle type, $F(1,9) = 8.519$, $p = .017$.

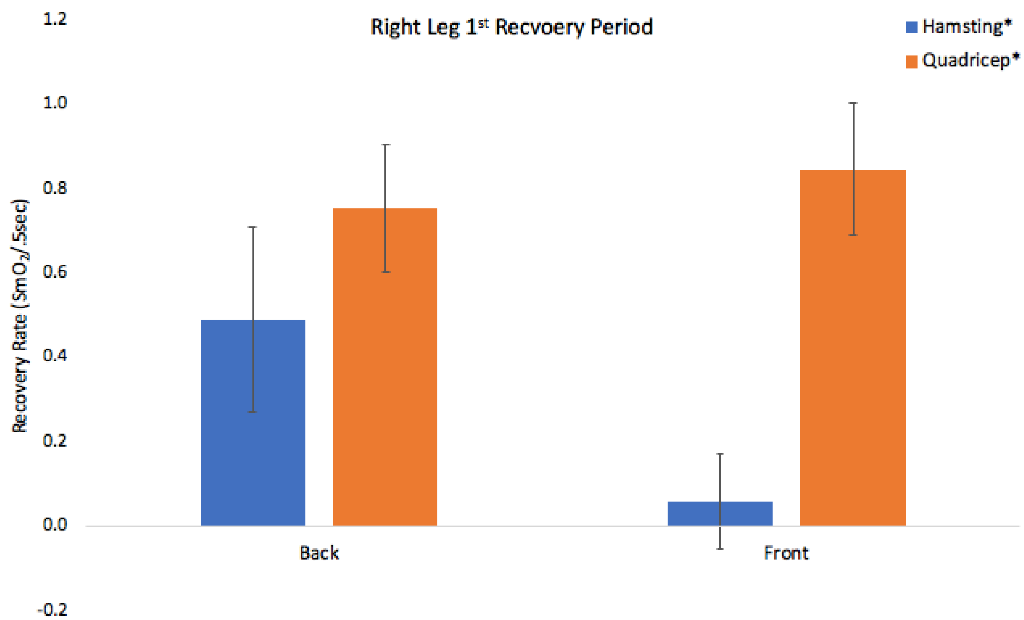

Figure 6. Right leg 1st recovery period. Recovery rate (mean ± SE) for first recovery period. See Table 3 for detail descriptive statistics. Significance level of $p < .05$ denoted by *.

For the second recovery period (n=10); there was a significant main effect of squat type, $F(1,9) = 7.435$, $p = .023$. The was a significant main effect of muscle type, $F(1,9) = 8.781$, $p = .016$. However, there was not a significant difference between the interaction of squat type and muscle type, $F(1,9) = .145$, $p = .712$.

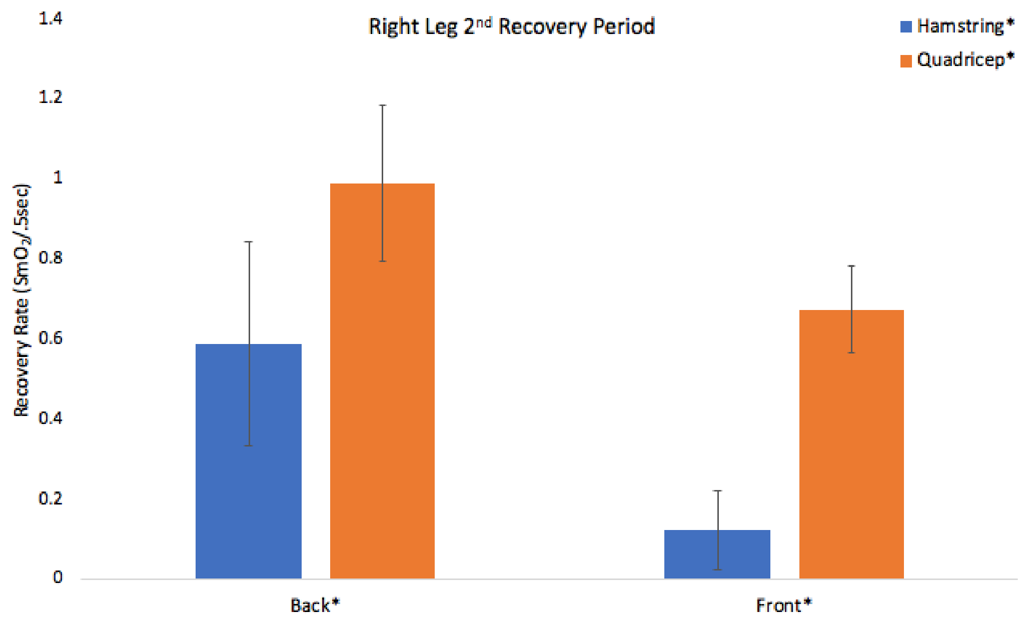

Figure 7. Right leg 2nd recovery period. Recovery rate (mean ± SE) for first recovery period. See Table 3 for detail descriptive statistics. Significance level of $p < .05$ denoted by *.

For the third recovery period (n=10); there was not a significant main effect of squat type, $F(1,9) = 1.342$, $p = .277$. The was a significant main effect of muscle type, $F(1,9) = 9.609$, $p = .013$. There was not a significant difference between the interaction of squat type and muscle type, $F(1,9) = .119$, $p = .738$.

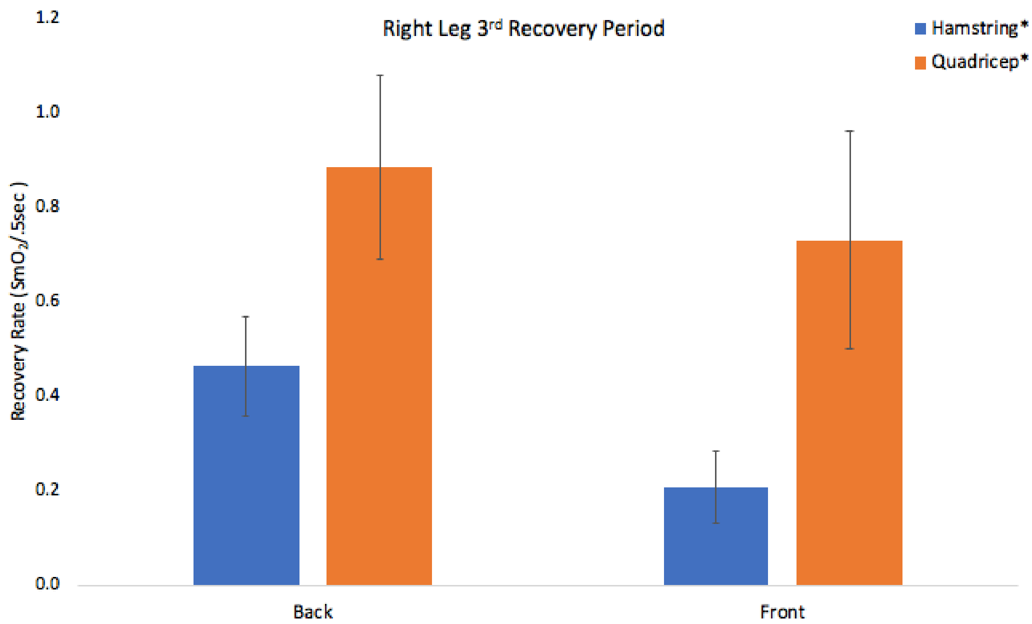

Figure 8. Right leg 3rd recovery period. Recovery rate (mean ± SE) for first recovery period. See Table 3 for detail descriptive statistics. Significance level of $p < .05$ denoted by *.

Table 3

Right Leg Descriptive Statistics

Rest Period	Squat Type	Muscle Type	Mean Recovery Rate (SmO_2/.5sec)	Standard Error
1 (n=10)	BS	BF*	.490	.218
	BS	VL*	.715	.150
	FS	BF*	.059	.113
	FS	VL*	.846	.155
2 (n=10)	BS*	BF*	.589	.255
	BS*	VL*	.991	.192
	FS*	BF*	.124	.098
	FS*	VL*	.673	.108
3 (n=10)	BS	BF*	.464	.106
	BS	VL*	.885	.194
	FS	BF*	.207	.077
	FS	VL*	.730	.230

Note. BS = Back Squat, FS = Front Squat, BF = Biceps femoris, VL = Vastus lateralis. Significance level of $p < .05$ denoted by *.

Left Leg Analysis

For the first recovery period (n=11); there was not a significant main effect of squat type, $F(1,10) = 1.150$, $p = .309$. The was a significant main effect of muscle type, $F(1,10) = 6.466$, $p = .029$. There was not a significant difference between the interaction of squat type and muscle type, $F(1,10) = 1.612$, $p = .233$.

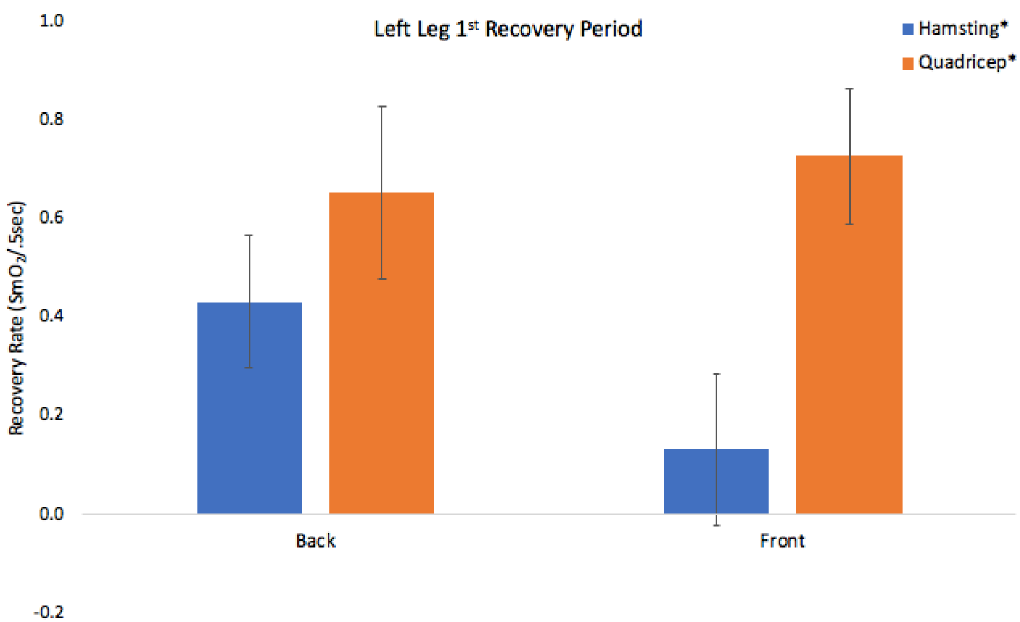

Figure 9. Left leg 1st recovery period. Recovery rate (mean ± SE) for first recovery period. See Table 4 for detail descriptive statistics. Significance level of $p < .05$ denoted by *.

For the second recovery period (n=11); there was not a significant main effect of squat type, $F(1,10) = .250$, $p = .628$. The was a significant main effect of muscle type, $F(1,10) = 5.952$, $p = .035$. However, there was not a significant difference between the interaction of squat type and muscle type, $F(1,10) = .002$, $p = .964$.

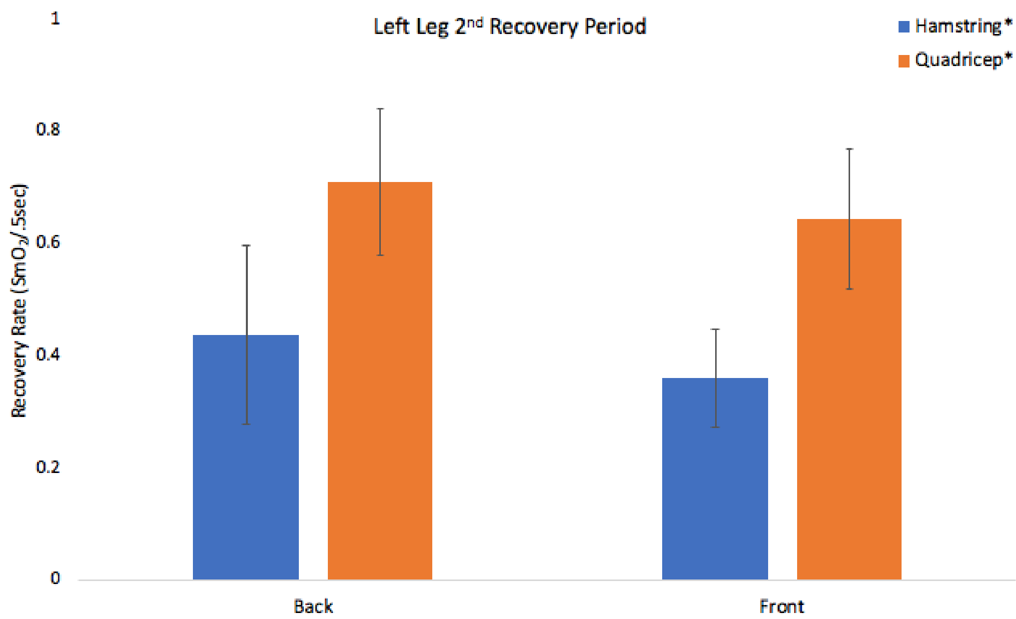

Figure 10. Left leg 2nd recovery period. Recovery rate (mean ± SE) for first recovery period. See Table 4 for detail descriptive statistics. Significance level of $p < .05$ denoted by *.

For the third recovery period (n=11); there was not a significant main effect of squat type, $F(1,10) = .097$, $p = .762$. The was a significant main effect of muscle type, $F(1,10) = 14.754$, $p = .003$. There was not a significant difference between the interaction of squat type and muscle type, $F(1,10) = .011$, $p = .920$. SmO_2/.5sec

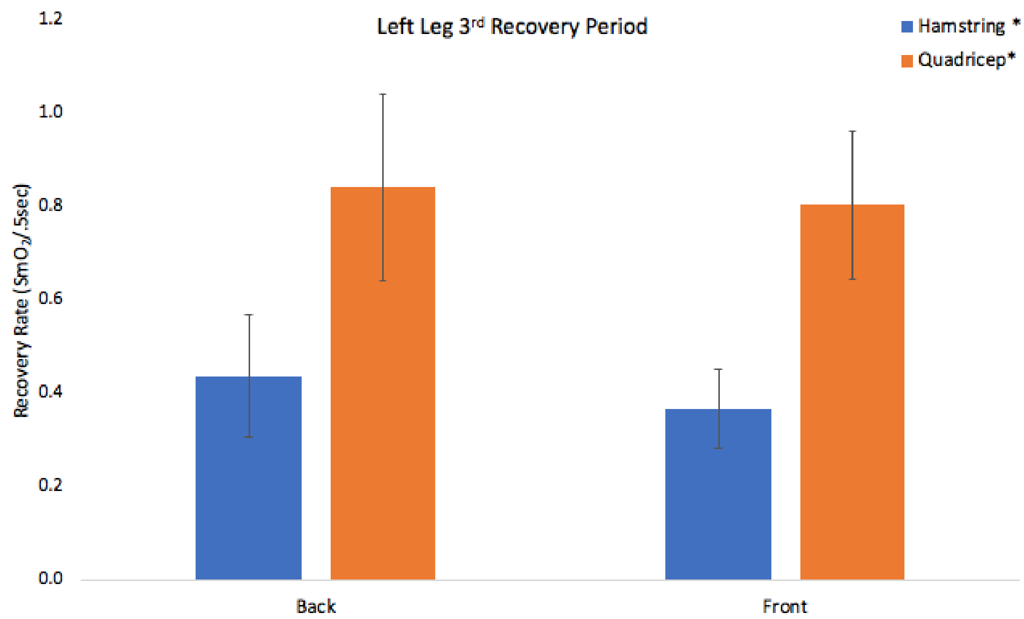

Figure 11. Left leg 3rd recovery period. Recovery rate (mean ± SE) for first recovery period. See Table 4 for detail descriptive statistics. Significance level of $p < .05$ denoted by *.

Table 4

Left Leg Descriptive Statistics

Rest Period	Squat Type	Muscle Type	Mean Recovery Rate (SmO_2/.5sec)	Standard Error
1 (n=11)	BS	BF*	.432	.135
	BS	VL*	.654	.175
	FS	BF*	.132	.155
	FS	VL*	.727	.138
2 (n=11)	BS	. BF*	.438	.159
	BS	VL*	.710	.131
	FS	BF*	.360	.087
	FS	VL*	.644	.125
3 (n=11)	BS	BF*	.436	.131
	BS	VL*	.840	.201
	FS	BF*	.366	.085
	FS	VL*	.803	.158

Note. BS = Back Squat, FS = Front Squat, BF = Biceps femoris, VL = Vastus lateralis Significance level of $p < .05$ denoted by *.

CHAPTER V

Discussion

The purpose of this study was twofold: first to determine if SmO_2 recovers faster when comparing hamstring or quadricep muscles and second to determine if SmO_2 recovers faster when comparing front or back squats at 70% of an individual's 1-RM weight of each designated lift using the MOXY sensor.

In this study, one hypothesis was there would be no difference between the SmO_2 recovery rates between hamstring and quadricep muscles. The main findings of this study were able to determine there was a difference in recovery rates between the hamstring and quadricep muscles in both the left and right legs in all 3 rest periods. Therefore, the null hypothesis was rejected. The quadricep muscles had a greater recovery rate mean when compared to the hamstring muscle. With the greater recovery rate in quadricep muscles, it may suggest a faster recovery due to metabolic pathways, greater blood delivery, more capillarization, or greater muscle activation during the lifts compared to the hamstring muscles.

This greater recovery rate in quadricep muscles compared to hamstring muscles could be attributed to muscle fiber composition. There are two broad types of muscle fibers: type I (slow-twitch) and type II (fast-twitch). In studies about the hamstring muscles, type I fibers were reported at a lower percentage (30-50%) compared to a higher percentage of type I fibers in quadricep muscles (44-64%) (Jennekens, Tomlinson, & Walton, 1971; Johnson, Polgar, & Weightman, 1973). In type I muscle fibers, metabolic pathways are primarily aerobic (oxidative phosphorylation) due to the large number of mitochondria (McArdle, Katch, & Katch, 2015). Type I muscle fibers are more efficient at utilizing oxygen to produce ATP. In type II muscle fibers, metabolic pathways are primarily anaerobic (glycolysis) due to the short and rapid contraction speed (McArdle et al., 2015). A study by Azuma et al. (2000) examined similar recovery rates between the hamstring and quadricep muscles during knee extensions. The researchers suggested a greater recovery rate in quadriceps could be attributed to a high level of type I fibers. SmO_2 shows a relationship balance between the supply and demand of muscle oxygenation (Shibuya & Tanaka, 2003).

The difference in muscle type recovery is similar to findings presented in EMG muscle activation when comparing hamstring muscles and quadricep muscles (Fauth et al., 2010; Nishiwaki, Urabe, & Tanake, 2006; Slater & Hart, 2016). Nishiwaki et al. (2006) found an increased muscle activation in the vastus medialis (quadricep muscle) compared to two other hamstring muscles and one calf muscle in three different forms of squats when measure by EMG. Fauth et al. (2010) also found back squats are an adequate exercise to stimulate quadricep muscles. Researchers used EMG to measure muscle activation in the gluteal, quadriceps, and hamstring muscles in back squats, deadlifts, step-ups, and lunges. Only, in deadlifts were hamstrings the greatest muscle activated. From the findings in the present study and findings from the EMG studies, there may be a relationship between muscle activation and SmO_2 recovery rate.

During the 1st recovery period there was a significant difference between the interaction of squat type and muscle type. In this study, the other hypothesis was there would be no difference between the SmO_2 recovery rates between front squats and back squats. The only significant difference was during the 2nd recovery period for the right leg. With the limited supporting data, the null hypothesis was not rejected. When taking only into account the SmO_2 recovery rate, it does not matter which type of squat an individual selects to minimize recovery rate.

The results indicating no differences in squat type on SmO_2 recovery rate is similar to other EMG studies, except at maximal loading exercise (Gullett et al., 2009; Stuart, Meglan, Growney, & An, 1996). Yavuz, Erdağ, Amca, & Aritan (2015) investigated muscle activity during front squats and back squats at maximum load in 6 superficial leg muscles and one lumbar support muscle. Results showed in front squats there was increased muscle activation of the vastus medialis (quadricep muscle) when compared to back squats. Gullet et al. (2009) and Stuart et al. (1996) found no difference in muscle activation between front and back squats. Front and back squats were performed at 70% in the Gullet et al. (2009) study and 50 pounds in Stuart et al. (1996). The difference in the muscle activation findings could be related to reduce weight loading typically found in front squats compared to back squats.

Practical Implications

With NIRS monitors becoming more reliable and less expensive, these can be beneficial in SmO_2 research and personal training. Having a portable NIRS device to monitor oxygen utilization can be utilized in a variety of settings to track recovery rate of SmO_2. A portable NIRS device could provide valuable information for individuals looking to increase aerobic fitness. Ding et al., (2001) suggested SmO_2 recovery may be telltale of the aerobic training state and present the ability to increase utilization of O_2 capacity. Strength and conditioning coaches could utilize the NIRS devices to track peripheral fatigue when doing moderate to high intensity exercises. In real time, an individual would be able to tell when SmO_2 has recovered and when to start the next set.

Conclusion & Future Research

In conclusion, the hypothesis that there are no significant differences in SmO_2 recovery rates between front squats and backs squats was not rejected. There was only minimal data to support this hypothesis. The hypothesis of there are no significant differences in SmO_2 recovery rates between hamstring and quadricep muscles in each individual lift is rejected. The main findings of this study support the difference in SmO_2 recovery rates in different muscle types.

Future studies should compare SmO_2 recovery rates using the NIRS sensors to muscle activation using EMG in the quadricep and hamstring muscles. Previous studies have concluded a greater muscle activation in quadricep muscles when compared to other leg muscles (Nishiwaki et al., 2006; Slater & Hart, 2016). Future studies may also investigate SmO_2 utilization and recovery in front and back squats with a larger sample size.

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APPENDIX

Sam Houston State University
Consent for Participation in Research

Title: Tissue Oxygen Recovery Time Difference in Front and Back Squats

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Questions about the study: You may ask any questions you have at this time. If you have any questions, comments, or concerns about the research later, you can contact one of the researchers listed above. If you have questions about your rights while taking part in this study, or you have concerns or suggestions and you want to talk to someone other than the researchers about the study, please contact the administrator listed above.

Instructions: Please read this form carefully and take your time making a decision about participating. Please ask the researchers to explain any words or information you do not clearly understand. If you decide to participate, you may receive a signed copy of this form if desired.

Description: This is a research study. The purpose of this study is to determine if SmO_2 (muscle oxygen saturation) recovers faster in hamstring and quadricep muscles when comparing front squats or back squats at 70% of a person's calculated 1-repetition maximal weight of designated lift using a Moxy sensor.

Procedures: This study will require two sessions of assessments and two sessions of testing. Before participating in this study, you will complete a brief health history questionnaire to make sure you can safely complete the study. You will have your height, waist circumference measured, and report your date of birth. Then a body composition test on the Seca mBCA 514 scale. You will then have your parallel squat height measured with a goniometer and marked by a string. The order of testing (front vs back squat) will be randomized. For the assessment you will begin a warm-up of a 5-mintue cycling warm-up on a stationary bike and 6 stretches. Once the warm-up has been completed you will perform 3-5 form-practicing repetitions of your designated lift. Next you will perform weighted squats progressing to your one-repetition max weight. You will complete a 5-minute cycling cool down on a stationary bike. You will be required to perform testing session after 48 to 96 hours of rest after assessment session. For the testing session, researchers measure your parallel squat height again and will place Moxy sensors and EMG electrodes on your biceps femoris and vastus lateralis your right and left leg. You will perform another warm-up. Once the warm-up is complete, you will perform a warm-up set of 3 to 5 repetitions. Next you will perform 3 sets of 15 repetitions at 70% weight of your one repetition max weight with a 2 to 3-minute rest in between sets. After the completion of the 3rd set, you will rest for 15 minutes. You will then complete a 5-minute cycling cool down on a stationary bike. To normalize the data between participants, next you will perform an occlusion test for 5-minutes. An occlusion test, is similar to a blood pressure reading done at a doctor's office. An occlusion cuff is wrapped around your leg to reduce the blood flow, in order to find your lowest SmO_2 value. Once testing is completed, you will be scheduled for the second assessment and test of the study, which is exactly the same, as described above except for the other designated lift (front or back squat).

Duration of Involvement: Your participation will take approximately 45 minutes on 4 different occasions.

Number of Participants: Approximately 20 people are expected to participate.

Risks: The risks of participating in this study do not exceed those expected in normal activities for resistance-trained individuals. There is a slight risk of musculoskeletal injury associated with participating in exercise. To minimize this risk, you will complete a health history questionnaire to determine if you are likely to complete the session safely. Testing will also be closely monitored to ensure your safety. Compensation for an injury resulting from your participation in this research is not available from Sam Houston State University or the researchers. You retain your legal rights during your participation in this research.

In the event of injury related to this research study, you should contact your physician or the University Health Center. However, you or your third party payer, if any, will be responsible for payment of this treatment. There is no compensation and/or payment for medical treatment from Sam Houston State University for any injury you have from participating in this research, except as may by required of the University by law. If you feel you have been injured, you may contact the researcher John P. Yakel at (936) 294-1162.

Benefits: You will be able to use the one repetition max weight from both lifts to establish the load settings for an exercise program. The testing will allow you to determine the progress associated with an exercise program, and efficacy of that program.

Voluntary Participation: Your participation in the research is completely voluntary. If you decide to withdraw or not participate in this study, it will not change your current or future relations with Sam Houston State University.

Removal from the Research Project: The researcher(s) may also remove you from the project at any time and for any reason. Based on the assessment of the principal investigator, some of the reasons that you might be removed from the project are, but are not limited to the following:

- If you are not following instructions of your principal investigator or his/her assistants
- If the study is terminated
- If the investigator(s) has any concerns for your safety
- For any other reason at the discretion of the investigator(s)

If you are removed from the project for any reason, your project principal investigator will ask you to have a final evaluation. This evaluation could include any of the assessments/tests previously mentioned in this document and any other procedures that the project principal investigator feels are necessary. You may also be asked questions about your experience with the project.

Confidentiality: You will be assigned a code number to identify your data. Only the code number will be used for tracking purposes. Data will be stored in a locking filing cabinet. Only personnel directly involved in the study will have access to the data. Following completion of the study, the code key linking your name to your study results will be destroyed after one year.

The only people who will know that you are a research participant are members of the research team. No information about you, or provided by you during the research will be disclosed to others without your written permission, except:

- if necessary to protect your rights or welfare (for example, if you are injured and need emergency care or when the SHSU Protection of Human Subjects monitors the research or consent process); or
- if required by law.

Costs: There are no costs associated with participating in this research. You may wear your own lightweight apparel or research team will loan you lightweight apparel.

Compensation: You will receive promotional items (t-shirt, pen, keychain, etc.) from the Department of Kinesiology for participating in this study. The value of these promotional items will not exceed $10. Participants completing the testing session will receive promotional items. If you are removed from the study by the researcher(s), you will receive the promotional items. Some instructors, including research personnel, may provide extra credit for participation. See extra credit policy below for additional information.

Extra Credit Policy: Some instructors may provide extra credit for participating in research studies related to course work. It is the policy of the Department of Kinesiology that an equitable alternate activity also be offered. If your instructor has previously indicated extra credit may be earned through participating in research studies, you are responsible for providing the necessary documentation to the instructor. The researchers will provide a memo or ticket indicating your participation and time involved. This will not indicate if you completed the study or chose to withdraw. The time documented will be the anticipated duration of participant involvement.

Information about the role of students and course instructors is also available for your review from the researchers and is posted in the Human Performance Laboratory. If your instructor has not previously indicated extra credit may be earned through participating in research studies, you will not receive extra credit for participating in this research study.

Inclusion: If you are an adult (age 18 – 35) and have at least 6 months of prior weight training, you may be eligible to participate in this study.

Exclusion: If your health history indicates you are unlikely to be able to safely complete the exercise session, you are not eligible to participate in this study. This may include a recent back injury, heart attack or other musculoskeletal injury. If you are unable to speak and communicate in English, you will be excluded as the researchers are unable to communicate in any other language. If you have an electrical medical implant or pregnant you will be excluded from the study. If you do not meet the inclusion criteria you will be excluded.

If your health history indicates you are unlikely to be able to safely complete the exercise session, you are not eligible to participate in this study. This may include a recent back injury, heart attack or other musculoskeletal injury. Participants unable to speak and communicate in English will be excluded.

Right to Withdraw: You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

Informed Consent: I, ____, have read the description of this study, including the purpose of the study, the procedures to be used, the potential risks and side effects, the confidentiality, as well as the option to withdraw from the study at any time. The investigator has explained each of these items to me. The investigator has answered all of my questions regarding the study, and I understand what is involved. My signature below indicates that I freely agree to participate in this experimental study and that I have received a signed copy of this agreement if desired from the investigator.

Participant:____ Date:________________

Witness:____ Date:________________

VITA

John P. Yakel

Education

- ***B.A. in Health, Exercise, & Sports Science***, University of the Pacific, Stockton, CA,
- ***M.S in Sport & Human Performance,*** Sam Houston State University, TX, expected December 2018
- ***CPR/First Aid Certification,*** Valid through June 2020
- ***Lakewood High School**,* Lakewood, CA, Cum Laude, Graduated June 2012

Work Experience

- ***Sam Houston State University, Huntsville, TX*** October 2016- Present
  - Kinesiology Graduate Teaching/Research Assistant
    - Direct and maintain all activities in the Human Performance Laboratory and Biomechanics Laboratory
    - Collaborate and assist professors on current research paper focusing on sport performance/medicine
    - Guest laboratory teacher and guest online lecturer
    - Coordinate equipment install and maintenance
- ***La Torretta Lake Resort & Spa, Montgomery, Tx*** September 2016 – Present
  - Golf Assistant
    - Schedule, supervise, and train outside staff
    - Assistant Head Golf Professional with merchandising duties
    - Coordinate tournaments and outings
    - Coordinate Golf Membership activities: monthly social events and golf tournaments
    - Maintain the Golf Handicap computer and associated records
    - Golf operation background
- ***First Base Foundation, Mill Valley, CA*** Summer 2016
  - Summer Collegiate/High School Baseball Coach
    - Prepared athletes for the physical and mental aspects of entering a collegiate baseball program
    - Assisted in scheduling duties
    - Communicated with young players to help them achieve a better knowledge of the game of baseball
    - Worked with players in one on one setting outside of practice to improve their skills
    - Interacted with players' parents in order to ensure satisfaction with the services that Headfirst provided

Volunteer Experience

- ***Orthopedic Physical Therapy Institute, Modesto, CA*** Summer 2016
    - Observation Student
        - Assisted with daily routines/duties in the facility
        - Assisted in various areas with patients and their rehab exercises
- ***Pacific Baseball, Stockton, CA*** 2010-2015
    - Physical Activity Coordinator
        - Planned activities for local Elementary Schools
        - Assisted in teaching the activities to the children in the class

Research Projects

- ***Sam Houston State University, Huntsville, TX***
    - **Accuracy of Smartphone Application to Monitor Heart Rate**
        - 2017 ACSM Abstract poster presentation (Denver, CO)
    - **Prevalence of Sarcopenia in the General Population**
        - 2018 ACSM Abstract poster presentation (Minneapolis, MN)
    - **Tissue Oxygenation Recovery Time Difference in Front and Back Squats**
        - Graduate Thesis

Awards

- ***Collegiate Baseball Letterman 2012-2013, 2013-2014,2014-15,2015-2016***
        - Captain 2014-2015, 2015-2016
- ***West Coast Conference Baseball All-Academic Team 2013-2014, 2014-2015***